ENGINEERING CASE LIBRARY

ECL 199

AMPHIBIOUS VEHICLE MODELS: CALIBRATION AND TESTING

To determine the propulsive power requirements for a new amphibious vehicle, FMC Corporation ran tests on a scale model. This type data permits adjustments before an actual prototype is built.

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FMC Corporation in San Jose, California, produces, among other products, amphibious vehicles. Although primarily used on land these vehicles must be capable of attaining velocities of 3 to 4 miles per hour in the water. In designing a new vehicle to meet these specifications, FMC uses models to test buoyancy, drag, and waterborne attitude. Exhibit 1 shows one such model being towed on a test run. Note the adjustable trim vane (front of model) and the adjustable linkage which holds the model to the test apparatus. Exhibit 2 shows the linkage and instrument placement in detail.

The test engineer wishes to measure the drag force on the model. Attaching any type of spring or force gage directly to the model would interfere with its design characteristics, thereby invalidating the test. This means that the engineer must attach his measuring device to the test apparatus itself. He must also attach the model in such a way that the only force transmitted to it is equivalent to the desired propulsive force and acting at the same point of application. (An actual vehicle of this type is propelled in water by the movement of its tracks.) The engineer, therefore, measures the bending moment in the support column caused by the drag force on the model.

Because there is no way to measure the stress in the support column directly, the test engineer uses a strain gage located as shown in Exhibit 2. Strain gages can be constructed from very fine wire (.001 inch diameter) or through photochemical techniques as are printed electrical circuits. Once the gage is glued to the test piece, the resistance of the electrical circuit will change as the length of the wire changes. This corresponds to the changes in the surface strain of the material. Using the appropriate stress-strain relationships, the engineer can then calculate the moment acting at the gage and, from this, the force acting on the test piece.

Before the model is attached to the test apparatus, the strain gage must be calibrated. This is done by applying a force of 1 pound to the upper pivot of the linkage. (Force F_c, Exhibit 2). To use the reading as a proportionality factor, the recorder is set to a convenient 10 lines to correspond to the one pound calibration force, F_c.

FMC engineers also wished to find the actual stress in the support column. A high stress was desirable in order to give more accuracy to their measurements. At the same time the stress could not exceed the elastic limit of the material. At the section where the strain gage is attached, the column

is 2.25 inches wide and 0.125 inches thick. It is made of aluminum alloy.

In the vertical direction, the linkage assembly is carefully balanced so as to apply no forces to the floating model.

FMC engineers rely on past experience with similar designs to dictate the desired amount of freeboard and the attitude of the model in the water. Freeboard is decreased by adding ballast to the free floating model. Trim vane adjustments bring the moving model to the desired attitude, and the linkage is adjusted to accommodate this attitude. (Read on the inclinometer shown in Exhibit 1.) After all adjustments are complete the apparatus is again checked to insure that no vertical force is transmitted between the model and the linkage. Linkage dimensions are then measured. These are recorded in Exhibit 2.

Finally the test is conducted by towing the model through the test channel at speeds which represent the desired vehicle speed, and recording the output of the strain gage.

STUDENT QUESTIONS:

1. Draw a free body diagram of the model attached to the test apparatus and being towed through the water. Show approximate location of the center of gravity of the model. Find the exact location of the point of application of the propelling force, F_p.

2. Draw a free body diagram of the actual personnel carrier as it moves through the water.

3. Why were FMC engineers interested in preventing the model from exerting any vertical force on the support column?

4. Calculate the stress in the support column at the strain gage for the one pound force F_c. What is the strain at that point?

5. A recorder reading of 25 lines was observed during the test. F_d, shown in Exhibit 2, is a drag force of unknown magnitude and location. What is the magnitude of F_d required to produce the observed reading? What is the actual strain?

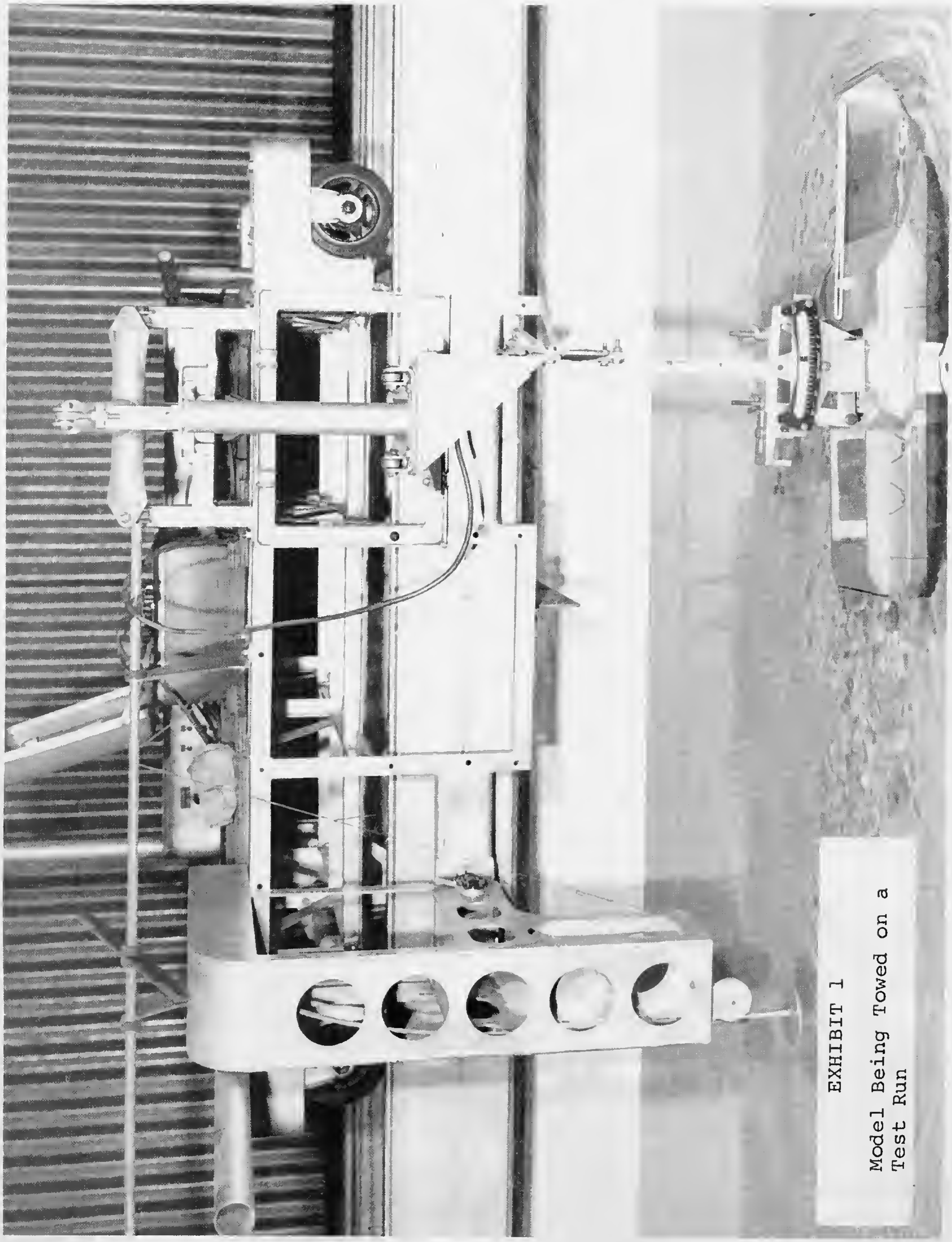


EXHIBIT 1

Model Being Towed on a Test Run

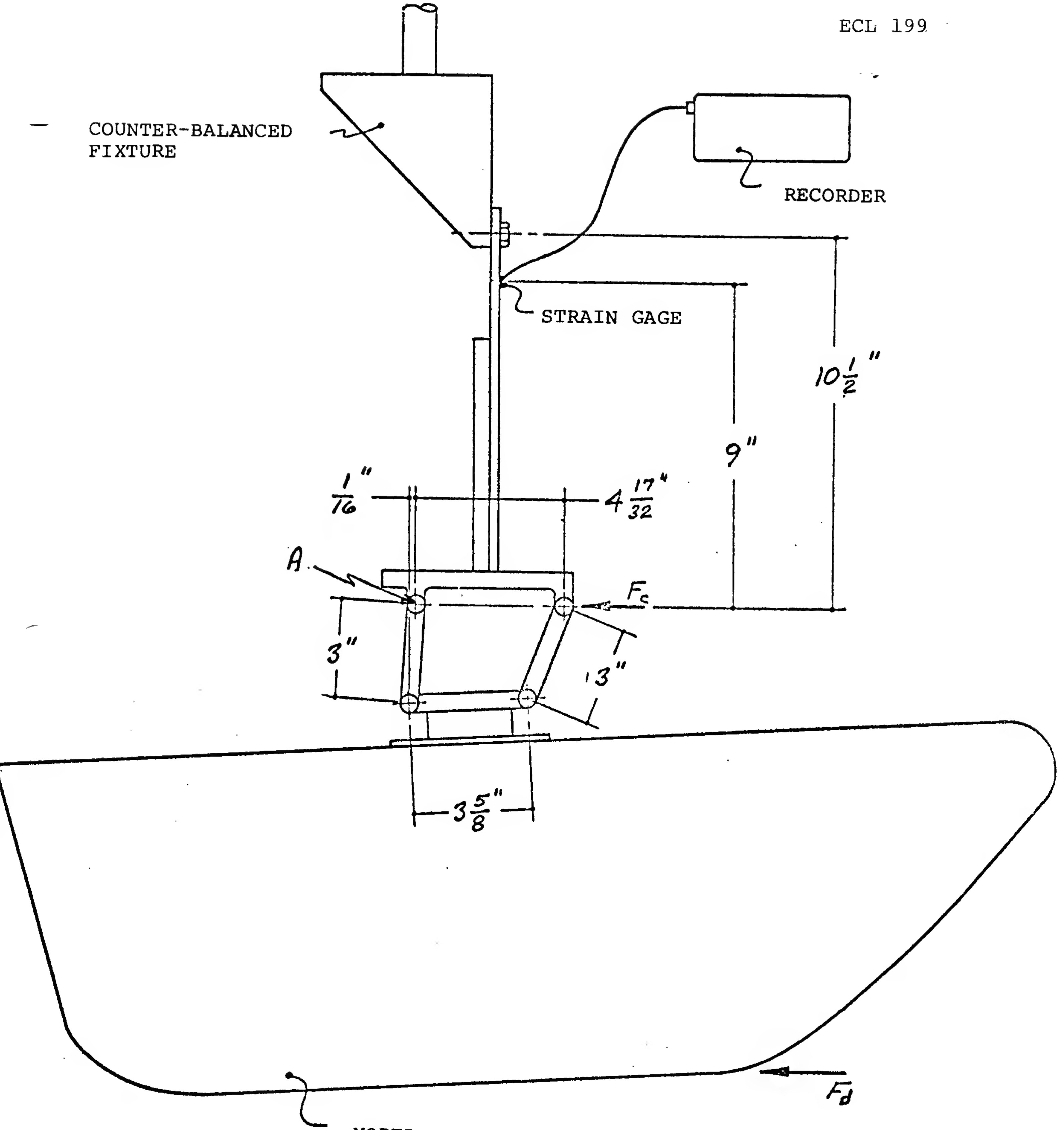


EXHIBIT 2

Linkage and Instrument Placement

INSTRUCTOR'S NOTES

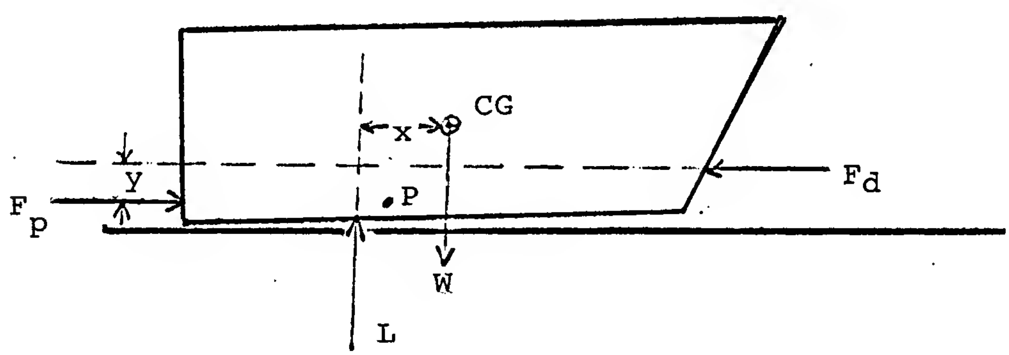
1. The vehicle in the water can support neither resultant forces nor moments. If any are applied, the model will shift its attitude until it reaches a new equilibrium position. For the stationary model the lift equals the weight. Their lines of action are collinear and pass through the center of gravity of the model. We must show this same equilibrium on the free body diagram of the moving model.

To show accurately the forces acting on the moving model requires more information than we now have. The lift and the drag are both distributed forces whose magnitude we can find but whose lines of action are not known. The lift, now composed of the buoyancy and the aerodynamic lift, but still equal in magnitude to the weight, shifts to the rear of the CG with the change in model attitude. The lift and weight then produce a couple on the model. The lines of action of the propelling and drag forces, therefore, must be offset by some distance, y, in order to form a couple equal in magnitude but opposite in direction.

The equation needed to place the boat in equilibrium is:

$$F_p(y) = L(x)$$

with unknowns x and y



Since they knew where the point, P, was but did not know x or y, FMC engineers actually calculated the propulsive force, F_p, which would equal the drag in magnitude.

2. If the model is accurately designed, the free body diagram for the actual vehicle should be identical to that of the model.

3. Any vertical force by the model on the support column would appear on the recorder output for the strain gage. It would be impossible to resolve this reading into its three component strains: that caused by the moment of the force F_d (the desired quantity), that caused by the axially loaded support column, and that caused by bending moments resulting from the support column being eccentrically loaded.

4. This problem requires a knowledge of strength of materials but should not be beyond the scope of the statics student if the necessary formulae are briefly explained by the instructor. An alternative approach would be to use this question as an illustrative classroom example of how the test apparatus would be further analyzed.

The plane stress assumption may cause error of up to 10% since the "beam" is actually a thin plate. This simplified view is the one actually used by the engineers, however, and is quite adequate.

Instructor may emphasize that F_c has a 9" rather than a 10.5" moment arm.

Stress due to one pound force F_c:

$$\sigma = \frac{Mc}{I}$$

$$M = (1\text{ lb.})(9\text{ in}) = 9\text{ in-lb}$$

$$c = \frac{.125}{2} = .0625\text{ in}$$

$$I = \frac{bh^3}{12} = \frac{(2.25)(.125)^3}{12}$$

$$= .367 \times 10^{-3}\text{ in}^4$$

$$= \frac{(9\text{ in-lb})(.0625\text{ in})}{.367 \times 10^{-3}\text{in}^4}$$

$$= \underline{1535\text{ lb/in}^2}$$

Strain: Assume plane stress ; no lateral stresses on beam.

$$e_{xx} = \frac{1}{E}\left(\sigma_{xx} - \nu\sigma_{yy}\right) \qquad E = 10 \times 10^6 \text{ psi}, \quad \sigma_{yy} = 0$$

$$= \underline{1.535 \times 10^{-4} \text{ in/in}}$$

5. The strain (and therefore the stress) is directly proportional to the bending moment in the support column. The magnitude of F_d can be found through a simple ratio of its associated moment with that of F_c. It was shown in Question 1 that F_p acts through point P and is equal in magnitude to F_d.

Magnitude of F_d

Force	Magnitude	Moment Arm	Recorder Reading
F_c	1 lb.	9 in.	10
F_p	?	(9+14.1) in	25

$$\frac{F_p(9 + 14.1)}{25} = \frac{(1)(9)}{10}$$

$$F_d = F_p = \underline{.975 \text{ lb.}}$$

Strain caused by F_d:

$$\frac{e_{F_c}}{10} = \frac{e_{F_d}}{25}$$

$$e_{F_d} = \left[\frac{1.535 \times 10^{-4}}{10}\right] 25$$

$$= \underline{3.99 \times 10^{-4} \text{ in/in}}$$

The actual stresses (1535 lb/in^2 and 3990 lbs/in^2) are well below the yield strength of aluminum alloy. They are, however, high enough to insure accurate readings.